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Plastic marine debris on the Portuguese coastline: A matter of size?

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ABSTRACT

Plastic debris is a worldwide threat to marine environments and Portugal is not immune to it. Though never quantified, items of all sizes can be found in the Portuguese coastline; therefore the objective of this work is the identification of main size classes in stranded plastic debris. Beaches sediment was sampled and in the laboratory plastic items were sorted in 11 classes from <1 to >10 mm, counted and weighted. Plastic size ranged from 50 µm to 20 cm and microplastics (<5 mm) were the majority (72%). Most plastic fits in the smaller size classes, due to expected high residence time in the sea enhancing degradation processes, which increase surface exposure and potentially persistent organic pollutants (POP) adsorption. These results point out the important contribution of microplastics to marine debris pollution, its risks, and the need to set a higher focus on this size class.

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Plastic marine debris accumulation and dispersal is a growing problem at a global scale, affecting all marine environments (Gregory, 2009; Moore, 2008). The high persistence of plastic material, together with poor lifecycle management, high production (Andrady and Neal, 2009), consume and discard habit (Hopewell et al., 2009), concentration of population on the coast, and consequent disposal of high volumes of plastic that poorly handled may enter the water streams, accumulate in the oceans and along the coastlines, to where they are carried by the wind and currents. Regarding this last factor, land sources are responsible for 70–80% of plastic in the marine environment (Bowmer and Kershaw, 2010).

The importance of plastic debris in the marine environment was first noticed by visual impact of plastic dispersed throughout the oceans and physical direct impacts on marine biota, i.e., entanglement and death. Nowadays, main focus is set at the ingestion of plastic (Bockstiegel, 2010). Microplastics, defined as plastic with diameter less than 5 mm (Arthur et al., 2008), and its impacts on the marine ecosystem are starting to receive more attention (Gorycka, 2009).

Beach litter surveys, ocean monitoring programs and collected plastic analysis show that there are reasons for concern: physical impairment on marine fauna, ecotoxicological effects from ingestion of plastics due to adsorption of persistent, bioaccumulative and toxic pollutants (PBT as polychlorinated biphenyl – PCB and dichloro-diphenyl-trichloroethane – DDT and plastic additives), exotic species transport and several economical and social implications.

Additionally, expected degradation and fragmentation of plastics in the marine environment is a result of highly variable factors, and has never been studied thoroughly, therefore it is not possible to predict the amount or size of the resulting plastic fragments as their residence time in the sea increases. It is essential to get data on the size of plastic debris, especially the smaller size classes in order to estimate the magnitude of the problem.

Monitoring the abundance of plastic marine debris has been performed in many countries but Ivar do Sul and Costa (2007), Moore (2008) and UNEP (2009) point out that the smaller plastic fractions (<20 mm) are not usually discriminated due to sampling difficulties, so its sources, destiny and environmental consequences are poorly understood (Sheavly and Register, 2007). However, it is known that microplastics are globally dispersed in the oceans, and that plastics degrade and become smaller and smaller, reaching unknown sizes, posing a long-term threat to the marine food chains, through ingestion.

The coast of Portugal is vulnerable to plastic accumulation on beaches from land sources due to river discharges and population concentration along the coast, marine sources due to fishing and recreational maritime activities, as well as being an important route for commercial vessels and cruise ships. The objective of this study is to identify the more important size categories of plastic (from <1 to >10 mm) accumulating on the coastline. Additionally, selected plastics were chosen for the identification of the common polymers present.

Beaches were chosen on the basis of their accessibility and orientation to the dominant north-western winds, in order to maximize the probability of debris accumulation. Samples were collected during the equinoctial spring tides of March 2010 at five beaches on the western coast of Portugal (Fig. 1): Agudela (41°23′1.25″N 8°46′16.34″W), Cova de Alfarroba (39°21′37.67″N 9°21′45.78″W), Cresmina (38°43′28.16″N 9°28′34.61″W), Fonte da

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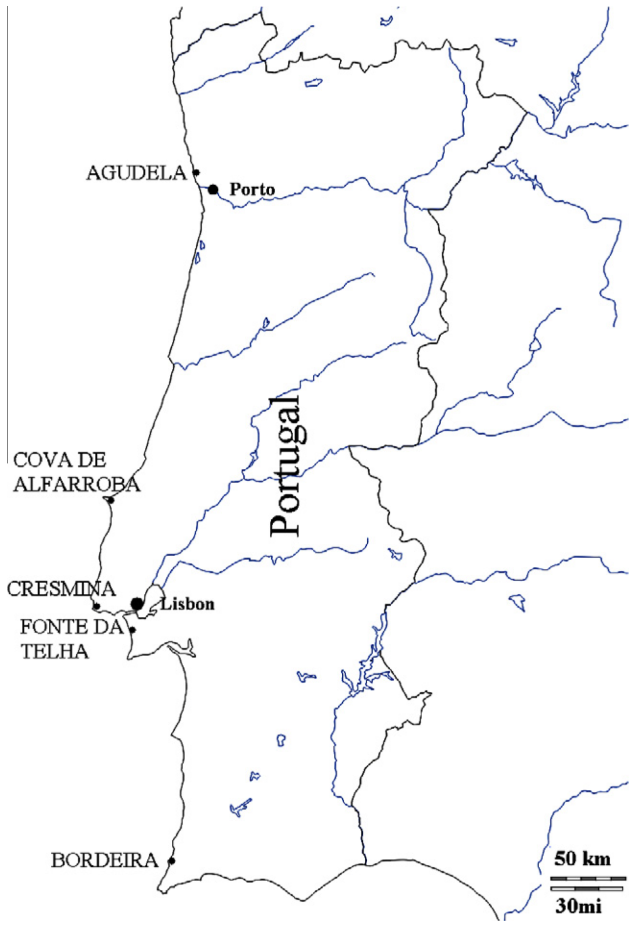

Fig. 1. Sampling sites on the Portuguese coast.

Telha (38°34′9.15″N 9°11′40.40″W) and Bordeira (37°11′50.69″N 8°54′14.55″W).

Sampling was performed by using quadrats placed along the last high tide mark, as plastic is preferably accumulated in this zone. Two sizes of quadrats were used in triplicate: (A) 0.5×0.5 m and (B) 2×2 m. The top 2 cm of sand were scooped from each quadrat area, A samples were placed directly in paper bags and B samples were sieved *in situ* using a commercial 2.5×3.5 mm metal mesh size, to discard the sand and retain the debris.

In the laboratory, A samples were introduced into a glass tank with a concentrated solution of NaCl (140 g L^{-1}), stirred vigorously and the floating plastic particles recovered. This procedure was repeated several times until no particles could be seen on the sediment. The water was then filtered with a GAST vacuum pump, onto Whatman® GF/C filters (~1 μm pore size and 47 mm diameter) to recover any plastic pieces of minor dimensions, not visually identified in the solution. For B samples plastic was set apart from the remained debris.

All plastic pieces were classified, counted and weighted, according to the size classes adopted by Ogi and Fukumoto (2000): class 1 (⩽1 mm), class 2 (>1 mm and ⩽2 mm), class 3 (>2 mm and ⩽3 mm), class 4 (>3 mm and ⩽4 mm), class 5 (>4 mm and ⩽5 mm), class 6 (>5 mm and ⩽6 mm), class 7 (>6 mm and ⩽7 mm), class 8 (>7 mm and ⩽8 mm), class 9 (>8 mm and ⩽9 mm), class 10 (>9 mm and ⩽10 mm), class 11 (>10 mm).

Filters from A samples were observed through a binocular microscope and all the material visually identified as plastic was measured and counted.

Polymer identification was performed on selected items by Infra-red Spectroscopy with Fourier Transformation using a Thermo® Nicolet Nexus spectrometer interfaced with a Continuum microscope (Micro-FTIR). All the acquired FTIR spectra were obtained in transmission mode and CO_2 interference (absorption at approx. 2300–2400 cm^{-1}) was removed for clarity. The spectral images were compared with standard ones in a database using the Software Thermo Nicolet OMNIC®.

For the five beaches a total amount of 17799 plastic items (~2322 g), was collected with average density of 185.1 items m^{-2} (average weight of 36.4 g m^{-2}). Size ranged between 50 μm and 20 cm in diameter (excluding microplastics from filters for polymer identification).

The distribution of total abundance according to size for all beaches is shown in Fig. 2. The discriminated average densities of items per square meter, for each size class and each beach are shown in Fig. 3.

Plastic abundance is higher for classes 3, 4 and ⩽5 mm, representing 60% of total abundance, as size deviates from these size range, abundance decreases, with exception of class >10 mm (10% of total abundance). Microplastics, ⩽5 mm, correspond to 72% of total abundance.

High discrepancies are found between the obtained abundances, with inter- and intra-beaches variations, as it can been seen in the following values of average densities: 392.8 items m^{-2} in Cova de Alfarroba, 301.2 items m^{-2} in Fonte da Telha, 103.7 items m^{-2} in Cresmina, 99.1 items m^{-2} in Agudela, and finally 28.6 items m^{-2} in Bordeira. In particular, the average densities per beach are: highest at size 4 mm for Agudela, Cova de Alfarroba and Cresmina and size 3 mm for Fonte da Telha and Bordeira; and lowest at size 1 mm for Agudela, Cova de Alfarroba, Cresmina and Bordeira and size 9 and 10 mm for beach Fonte da Telha, and also beaches Agudela and Bordeira.

Fig. 4 shows the weight distribution for the size classes defined. Regarding weight, as expected, there is a predominance of plastic from size class >10 mm, corresponding to ~90% of total weight.

In the lower end of size range, i.e., group of particles retained on filters more than a hundred items were visually identified as plastic under a stereoscopic microscope. Results from polymer identification by micro-FTIR are presented below for some of the analyzed particles (Fig. 5). The accuracy probabilities (%) for polymer identification are defined according to Thermo Nicolet® OMNIC FTIR database.

Stranded marine debris abundance is mainly correlated to physical factors – distance to sources, form, physiography and orientation of beach. Regarding abiotic factors, the most important are wind direction, superficial waves and currents (Debrot et al., 1999). The total abundance of plastic accumulated in the five

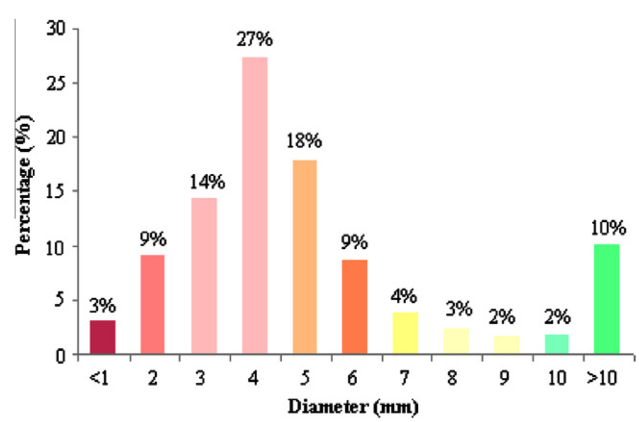

Fig. 2. Plastic abundance (%) for each size class (mm) – five beaches.

Plastic size classes (mm)	Average distribution of plastic abundance (items.m^{-2})				
	Agudela	Cova de Alfarroba	Cresmina	Fonte da Telha	Bordeira
<1	2	3	1	21	1
2	8	12	9	50	5
3	17	45	13	58	5
4	26	137	29	53	4
5	14	94	18	36	3
6	8	41	8	21	2
7	4	15	4	11	2
8	4	10	2	6	1
9	2	6	2	5	1
10	2	6	3	5	1
>10	14	25	14	36	4
Total	99	393	104	301	29

Fig. 3. Average distribution of plastic abundance (items m^{-2}), per beach, for each size class (mm).

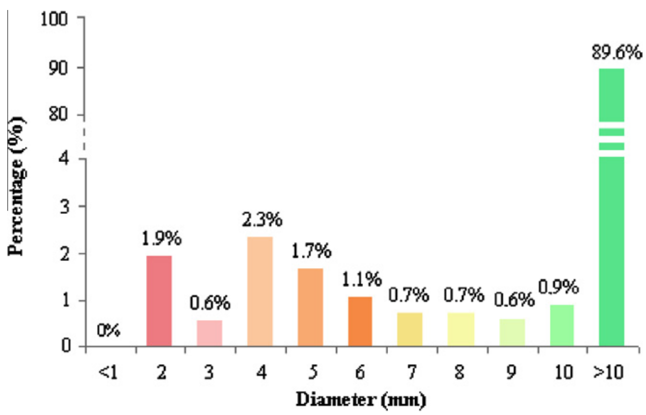

Fig. 4. Plastic weight (%) for each size class (mm) – five beaches.

beaches was very high – 925.4 items m^{-2}, possibly due to the match of sampling period with equinoctial high tides and beaches being north-oriented, influenced by northwest predominant currents, that promote higher rates of accumulation.

Beside these factors, beach sediment varies, and the smaller the grain size of sand the more it favors accumulation (Gregory, 2009). This was confirmed by the results obtained for each beach. As land sources are also relevant, identification of the proximity to these factors might help justify the obtained results. All beaches differed in sediment granulometry (not analyzed) and also in the proximity to land sources. Cova de Alfarroba beach (fine to medium sand), facing north and located near potential land sources, registered the highest average density of plastic items – 392.85 items m^{-2}, with more than 5000 items in the sampled area (12.75 m^2). In contrast, Bordeira beach with very fine sand had a very low average density – 28.6 items m^{-2}, possibly due to being located in one of the less populous coastal regions, compared with the other studied sites.

Plastic items density varies among regions and time. In comparison to other studies, Velander and Mocogni (1999) got 0.8 items m^{-2} for the Edinburgh coast, UK, while Barnes and Milner (2005) registered 0.15–12.5 items m^{-2} in different areas of North Atlantic Coast. At the northeast Brazilian Coast (along a distance of 150 km), an average density of 82.1 items m^{-2} was found by Santos et al. (2009) while in 2005 an average density of 76 items m^{-2} was registered, by Ivar do Sul (2005).

With respect to size, plastics with diameter less than 10 mm constituted 90% of total abundance, due to predominant pellets, polystyrene particles and other plastic fragments, the majority of them in the size range between 2 and 5 mm. In opposition more than 90% of plastic weight is related to plastics with diameter higher than 10 mm, due to the bigger items in this large size range class.

Regarding this size classes below 10 mm, Morét-Ferguson et al. (2010) in the North Atlantic Ocean identified 94% of plastic abundance, and Madzena and Lasiak (1997) got 33.3% for in South Africa. Costa et al. (2009) found 64.2% of plastic with diameter <20 mm in a beach of Brazilian northeast. Morét-Ferguson et al. (2010), in a long term study from 1990s to 2010s, registered an increase in plastic of smaller size classes in the North Atlantic Ocean, and suggest it could indicate the already mentioned "amplifying effects of mechanical abrasion and photochemical breakdown on particles with long residence time in the ocean".

Microplastics are predominant in the present study and account for ~72% of total abundance. Other authors referred the importance of this particles size: Moore et al. (2001) report plastic between 1 and 2.8 mm in diameter corresponding to ~61% of the total, in California; McDermid and McMullen (2004) identified plastic between 2.8 and 4.75 mm corresponding to ~48% in a study focused on plastic between 1 and 15 mm in diameter, in Hawaii; and Morét-Ferguson et al. (2010) registered 69% of items between 2 and 6 mm, in the North Atlantic Ocean.

The high variability of average densities and micro- and macroplastic abundances is related to the several sites specific factors that regulate plastic debris accumulation and also to the different methodologies used by the different authors, therefore comparisons are limited.

From the group of items retained on filters the more important polymers were polyethylene (PE), polyester and polystyrene (PS). In other studies of polymer analysis in microplastics, Frias et al. (2010) found in two Portuguese beaches PE, PS and PP while Ng and Obbard (2006) found the same (PS being the most abundant polymer detected) and also nylon in samples from Singapore beaches. This is in accordance to the high industrial demand of these polymers (Plastics Europe, 2010). Polypropylene however was not found in our samples.

Results of this study show that plastic waste in Portuguese coast is a problem, particularly in the smaller size range. Plastic pellets are frequently found floating in the sea, in the same layer were concentrations of PBT contaminants are known to be high (Wurl and Obbard, 2004). Also, the higher the residence time of plastic in the sea, the more enhanced are degradation processes, promoting higher surface/volume ratios, which may result in higher concentrations of PBT contaminants. To worse it, Endo et al. (2005) and Frias et al. (2010) got respectively – higher PCB concentrations in aged polyethylene pellets and higher DDT, PCB and polycyclic aromatic hydrocarbon (PAH) concentrations in colored pellets, respectively, than in the white ones. This is important since

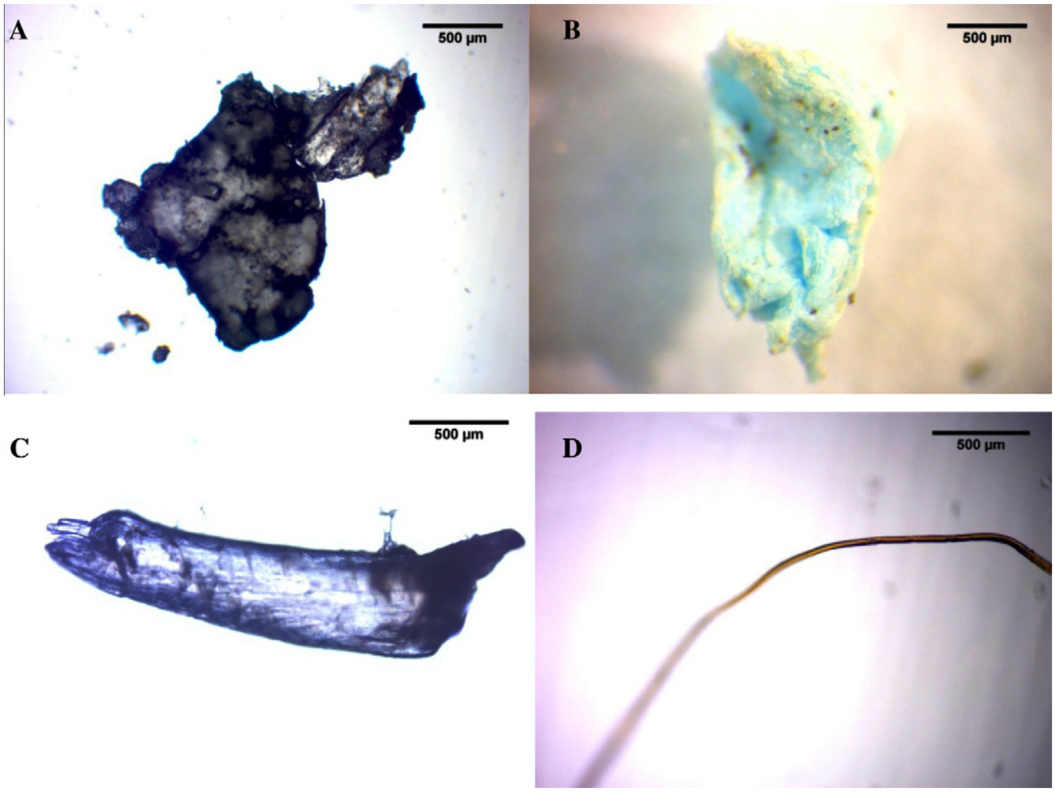

Fig. 5. (A) Polyethylene film (92.10%), (B) polystyrene (95.48%), (C) Berkley and Co. Berkley polyethyl (86.41%), (D) polyester (93.56%) analyzed using micro-FTIR spectroscopy (accuracy probabilities in %).

marine biota ingests preferably these types of pellets – colored pellets, as mistaken for food (Vlietstra and Parga, 2002). These facts might also be verified in other types of microplastics. Therefore it reinforces the need to propose solutions to prevent plastic debris from reaching the oceans and the importance of assessing, thoroughly, the contribution of microplastics to the pool of plastic debris on the oceans, as well as the potential risks from contamination and dispersal of smaller plastic particles.

An accurate evaluation of the influence of maritime and land sources, beaches physiography, form, orientation and dynamics, and meteorological conditions is essential to better understand the abundance of plastic of different size classes, in beach stranded plastic debris. In addition, including more beaches in the analysis, and a higher frequency of analysis, would better reflect the state of plastic marine debris accumulation in the Portuguese coastline.

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References

Andrady, A.L., Neal, M.A., 2009. Applications and societal benefits of plastics. Philosophical Transactions of the Royal Society B 364, 1977–1984. doi:10.1098/rstb.2008.0304.

Arthur, C., Baker, J., Bamford, H., 2008. Proceedings of the International Research Workshop on the Occurrence, Effects, Fate of Microplastic Marine Debris (NOAA Technical Memorandum NOS-OR&R-30). Tacoma, WA, USA.

Barnes, D.K.A., Milner, P., 2005. Drifting plastic and its consequences for sessile organism dispersal in the Atlantic Ocean. Marine Biology 146, 815–825. doi:10.1007/s00227-004-1474-8.

Bockstiegel, E., 2010. The North Pacific Gargabe Patch problems and potential solutions. SPEA 499 Honors Thesis. Indiana University, The United States.

Bowmer, T., Kershaw, P., 2010. Proceedings of the GESAMP International Workshop on micro-plastic particles as a vector in transporting persistent, bio-accumulating and toxic substances in the oceans. Reports&Studies n.82. UNESCO-IOC, Paris.

Costa, M.F., Ivar do Sul, J.A., Silva, J.S., Cavalcanti, S., Araújo, M.C., Spengler, Â., Tourinho, P.S., 2009. On the importance of size of plastic fragments and pellets on the strandline: a snapshot of a Brazilian beach. Environmental Monitoring and Assessment. doi:10.1007/s10661-009-1113-4.

Debrot, D.O., Tiel, A.B., Bradshaw, J.E., 1999. Beach debris in Curaçao. Marine Pollution Bulletin 38 (9), 795–801.

Endo, S., Takizawa, R., Okuda, K., Takada, H., Chiba, K., Kanchiro, H., Ogi, H., Yamashita, R., Date, T., 2005. Concentration of polychlorinated biphenyls (PCB) in beached resin pellets: variability among individual particles and regional differences. Marine Pollution Bulletin 50, 1103–1114. doi:10.1016/j.marpolbul.2005.04.030.

Frias, J., Sobral, P., Ferreira, A., 2010. Organic pollutants in microplastics from two beaches of the Portuguese coast. Marine Pollution Bulletin 60 (11), 1988–1992. doi:10.1016/j.marpolbul.2010.07.030.

Gorycka, M., 2009. Environmental risks of microplastics. Investigation Project. VrijeUniversiteit. Faculteit der Aard- en Levenswetenschappen. Holland.

Gregory, M.R., 2009. Environmental implications of plastic debris in marine settings – entanglement, ingestion, smothering, hangers-on, hitch-hiking and alien invasions. Philosophical Transactions of the Royal Society B 364, 2013–2025. doi:10.1098/rstb.2008.0265.

Hopewell, J., Dvorak, R., Kosior, E., 2009. Plastic recycling: challenges and opportunities. Philosophical Transactions of the Royal Society B 364, 2115–2126. doi:10.1098/rstb.2008.0311.

Ivar do Sul, J.A., Costa, M.F., 2007. Marine debris review for Latin America and the wider Caribbean region: from the 1970s until now, and where do we go from here? Marine Pollution Bulletin 54, 1087–1104. doi:10.1016/j.marpolbul.2007.05.004.

Ivar do Sul, J.A., 2005. Lixo marinho na área de desova de tartarugas marinhas do litoral norte da Bahia: consequências para o meio ambiente e moradores locais. Tese Monografia de Bacharelato. FURG, Brasil.

Madzena, A., Lasiak, T., 1997. Spatial and temporal variations in beach litter on the Transkei Coast of South Africa. Marine Pollution Bulletin 34 (11), 900–907.

McDermid, K.J., McMullen, T.L., 2004. Quantitative analysis of small-plastic debris on beaches in the Hawaiian archipelago. Marine Pollution Bulletin 48, 790–794. doi:10.1016/j.marpolbul.2003.10.017.

Moore, C.J., 2008. Synthetic polymers in the marine environment: a rapidly increasing, long-term threat. Environmental Research 108, 131–139. doi:10.1016/j.envres.2008.07.025.

Moore, C.J., Gregorio, D., Carreon, M., Weisberg, S.B., Leecaster, M.K., 2001. Composition and distribution of beach debris in Orange County, California. Marine Pollution Bulletin 42 (3), 241–245.

Morét-Ferguson, S., Law, K.L., Proskurowski, G., Murphy, E.K., Peacock, E.E., Reddy, C.M., 2010. The size, mass, and composition of plastic debris in the western North Atlantic Ocean. Marine Pollution Bulletin 60, 1873–1878. doi:10.1016/j.marpolbul.2010.07.020.

Ng, K.L., Obbard, J.P., 2006. Prevalence of microplastics in Singapore's coastal marine environment. Marine Pollution Bulletin 52, 761–767. doi:10.1016/j.marpolbul.2005.11.017.

Ogi, H., Fukumoto, Y., 2000. A sorting method for small plastic debris floating on the sea surface and stranded on sandy beaches. Bulletin of the Faculty of Fisheries Hokkaido University 51 (2), 71–93.

Plastics Europe, 2010. Plastics – the Facts 2010 An analysis of European plastics production, demand and recovery for 2009.

Santos, I.R., Friedrich, A.C., Ivar do Sul, J.A., 2009. Marine debris contamination along undeveloped tropical beaches from northeast Brazil. Environmental Monitoring and Assessment 148, 455–462.

Sheavly, S.B., Register, K.M., 2007. Marine debris & plastics: environmental concerns, sources, impacts and solutions. Journal of Polymers and the Environment 15, 301–305. doi:10.1007/s10924-007-0074-3.

UNEP – United Nations Environment Programme, 2009. Marine litter: a global challenge. Nairobi.

Velander, K., Mocogni, M., 1999. Beach litter sampling strategies: is there a best method? Marine Pollution Bulletin 38 (12), 1134–1140.

Vlietstra, L.S., Parga, J.A., 2002. Long-term changes in the type, but not amount, of ingested plastic particles in short-tailed shearwaters in the southeastern Bering Sea. Marine Pollution Bulletin 44, 945–955.

Wurl, O., Obbard, J.P., 2004. A review of pollutants in the sea-surface microlayer (SML): a unique habitat for marine organisms. Marine Pollution Bulletin 48, 1016–1030. doi:10.1016/j.marpolbul.2004.03.016.